Quintero-Duran, Marisol & Paul, Gunther
(2016)
Ergonomic assessment of a physical task using two different DHM systems. In
The 4th International Digital Human Modeling Symposium (DHM2016), 15-17 June 2016, Montreal, Canada. (Unpublished)

Comparison of Two Different DHM Systems for the Ergonomic Assessment of a Physical Task

M. QUINTERO-DURAN† and G. PAUL*†

† Queensland University of Technology, Victoria Park Road, Kelvin Grove QLD 4059 Australia

Abstract

The indirect and direct cost of occupational musculoskeletal disorders (MSDs) cause a significant burden on the health system, and lower back pain (LBP) is associated with a significant portion of MSDs. In Australia, there is a high prevalence of MSDs for health care workers, such as nurses. Two digital human models (DHMs) Siemens JACK and imk EMA were used to investigate if hospital bed pushing, a simple task and hazard that is commonly associated with LBP, can be validly simulated and ergonomically assessed in a virtual environment. While JACK and EMA have implemented a range of common physical work assessment methods, the simulation of a dynamic task such as bed pushing remains a challenge due to the complex interface between the environment, object, interface and other factors, which can only be insufficiently modelled. In addition, it was found that both human simulation systems present limitations that need to be considered during the interpretation of the results. This research highlights the limitations in the DHMs studied and the need for further research in the area. In particular, the implementation of legacy two dimensional, low resolution ergonomic methods in an analytic, high resolution three dimensional software system is critically reflected.

Keywords: SIEMENS JACK, imk EMA, virtual environment, pushing/pulling task, Digital Human Model.

1. Introduction

1.1. Ergonomic issues in hospital bed pushing/pulling

Moving patients during care activities is a common task for nurses (Petzäll, Berglund & Lundberg 1994). Pushing and pulling hospital beds is a form of manual material handling that has been linked with a high risk for the development of musculoskeletal disorders (MSDs). However, other than research into lifting tasks, the biomechanical or psychophysiological strain from pushing and pulling activities has been studied by far fewer researchers (Bhattacharya & McGlothlin 2012). In many hospitals, and particularly for bariatric patients, two or three nurses jointly move a hospital bed, further complicating kinematic conditions. This represents a potential bottleneck for the complete work system and a high risk of developing MSDs for the workers. Moreover, when pushing and pulling, high risk shear force is acting on the spine. Shear forces on spinal discs are considered to have a one third lower tolerance limit compared to tolerance limits for discs in compression (Waters, Lloyd, Hernandez & Nelson 2011).

Pushing and pulling when moving hospital beds include dynamic work, as the lower extremities are involved in a walking movement. On the other hand, the upper part of the body is involved in static work with isometric muscular contractions while controlling and steering the moving bed (Bennett, Todd & Desai 2011). Static load and effort reduce tissue blood supply through increased pressure on muscles, tissues, tendons and ligaments; consequently, this is an undesirable factor in the work system.

1.2. Digital Human Modelling

The use of virtual environments and DHM systems for evaluating specific scenarios such as hospital bed moving has a high potential in occupational health. When performed with real humans, ergonomic assessments may be costly, time consuming, tedious and may interfere with normal workplace activities. Therefore, the application of DHM systems to analyse the case of hospital bed moving overcomes these limitations. In addition, the application of DHM systems to analyse the case of hospital bed moving has not been studied yet. The significance of the study lies in the use of virtual environments and digital humans to evaluate a specific workplace case for a workplace population. Moreover, there will be no interference

*Corresponding author. Email: gunther.paul@qut.edu.au

with patient handling and normal workplace activities in the hospital environment. This study provides an analysis of possible differences and similarities between the two software tools used, as well as an assessment of generic issues in relation to the implementation of legacy ergonomic methods in ergonomic DHM systems.

Digital human modelling is a technology involving software representation of humans that is widely used in modern industry. DHM uses virtual environments and biomechanically accurate human figures to perform ergonomic analysis aiming to assess the feasibility and safety of a specific task (Bubb 2007). The use of DHM in the healthcare industry is of high importance. Generally, tasks in healthcare involve postures, movements and activities that are complex to simulate in experiments using real humans and environments (Ha, Cao & Khasawneh 2014). Therefore, the use of analytic studies represents a huge advantage when investigating and evaluating workplace scenarios in the healthcare industry.

Few studies applying DHM case scenarios in healthcare have been conducted. Most of them are focused on patient lifting and musculoskeletal disorders. This is the case of a study conducted by Ha, Cao & Khasawneh (2014) which subject is ergonomic assessment of patient lifting using digital human modelling, and a study conducted by Samson (2009) about digital human modeling for ergonomic assessment of patient lifting by paramedics. In addition, Cao (2011) presented a study focused on musculoskeletal disorders related to posture in sonographers. Most DHM studies however focus on the automotive sector, such as seminal compilations “Digital human modelling for vehicle design and manufacturing” by Paul, Reed, and Wang (2012); “Human motion simulation for vehicle and workplace design” by Chaffin (2007); and “Future applications of DHM in ergonomic design” by Bubb (2007).

2. Materials and Methods

2.1. Simulation in SIEMENS PLM JACK and imk EMA

The study comprises the ergonomic assessment of hospital bed moving using the two Digital Human Modelling (DHM) systems SIEMENS PLM JACK (Siemens AG, Munich) and imk EMA (imk automotive GmbH, Chemnitz). The results from simulations in the two different DHM systems are compared and analysed. The study exemplifies differences in workload assessment outcomes using the two tools. The ergonomic assessment performed in a virtual environment allows the variation of body proportions, in order to represent typical anthropometric conditions. Peoplesize V2.02 (Open Ergonomics Ltd, Melton Mowbray) was used to determine anthropometric dimensions not represented in the DHM databases. Common ergonomic methods used in the study are OWAS, RULA, NIOSH and metabolic energy expenditure (JACK), and EAWS (EMA).

The process used for the simulations is illustrated in Figure 1 and is similar to the one discussed in Ziolek (2000). In this approach, the simulation process is divided into three areas: environment, manikins and the actual analysis. In addition to these sections, tasks, posture and object positions are defined before the analysis phase.

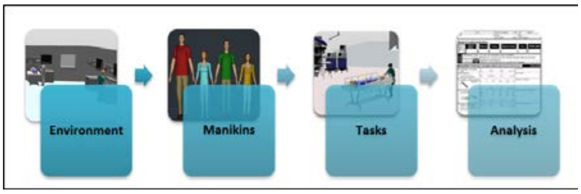

Figure 1. DHM simulation process.

For the digital environment design, the physical components of the case are taken into account, as the cognitive and psychological factors cannot yet be incorporated into the simulation. At this stage, input parameters such as loads and distances were established. CAD objects were either imported from a Google SketchUp CAD system library or were directly imported from the object library available in the software packages. The hospital bed was externally sourced.

In order to evaluate ergonomic workload, strain and job productivity, the software tool EMA uses EAWS (European Assembly Worksheet) and MTM- time analysis (Fritzsche et al., 2011). EAWS is based on a combination of standard tools for the assessment of workload such as posture and action forces.

Posture evaluation in EAWS considers “traditional” ergonomic evaluation methods/tools such as EN 1005-4:2005+A1:2008, ISO 11226 (2000), Toyota, OWAS and RULA.

The presentation of the results in EMA is in accordance with the structure of the EWAS screening tool where an overall evaluation is presented considering the following sections (Schaub, Caragnano, Britzke & Bruder 2013):

- Working postures and movements with low additional physical efforts
- Action forces of the whole body or hand-finger system
- Manual materials handling (load score)
- Repetitive loads of the upper limbs

After having completed each section, the software sums the individual results to obtain an overall score summary.

2.2. Hospital Bed and Anthropometric Dimensions

Common hospital bed geometry was selected as illustrated in Figure 2. A typical hospital bed weighs 200kg and when occupied, requires an initial pushing force of 350N on vinyl floors.

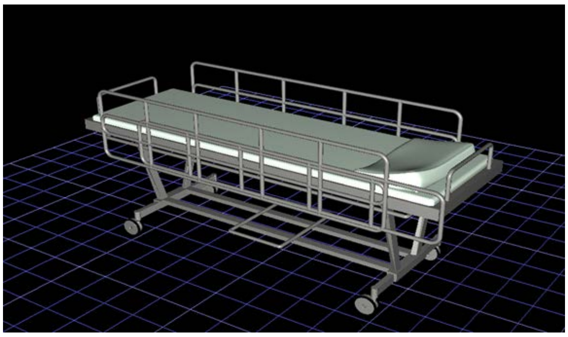

Figure 2. Hospital bed.

The ergonomic assessment performed in a virtual environment allows for variation of body proportions in order to represent typical anthropometric conditions. For the definition of the manikins, different anthropometric databases were considered. In JACK, humanoids can be scaled based on different anthropometric databases included in the package, or scaled based on weight and height measurements from external databases. In EMA, human models are predetermined on a German DIN population and it is not possible to scale them. The German 5th percentile stature female in EMA presents with 52kg of weight and is 40 years old. Even though it is possible to select gender and percentiles (5th, 50th, 95th) of the human models, other parameters such as nationality, age, weight and somatotype are pre-determined in EMA (V.1.5.1.0) and cannot be modified. Anthropometric data is also not extrapolated for the current date to reflect secular growth and up-to-date anthropometry. Additional manikins can be imported to the simulation, as can be seen in Figure 3, however, anthropometry measures cannot be adjusted nor can the manikins be used for ergonomic analysis. Consequently, those human models were used only for the purpose of creating the visual virtual hospital environment.

For the simulation in JACK, Chinese anthropometry was considered for the smallest (Chinese 5th percentile) boundary manikin, as the Asian population is the second largest ethnic group in Australia (Australian Bureau of Statistics (ABS), 2012) and it accounts for a high percentage of the Australian workforce.

In addition to the Chinese anthropometric data available in JACK, two more anthropometric dimensions needed to be specified for the Australian population (height and weight) based on Peoplesize data, in order to define the upper 95th percentile boundary manikin. The measurements not supplied were calculated by JACK using regression equations based on the US army data (ANSUR). Further model details for the study in JACK were specified in Paul & Quintero-Duran (2015).

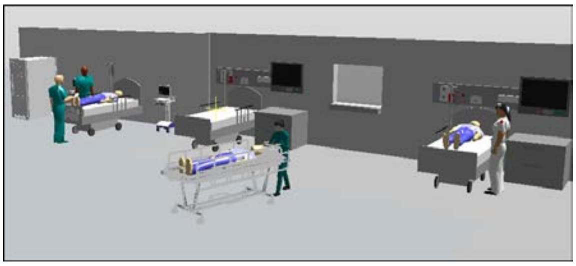

Figure 3. Virtual hospital environment.

3. Results

Results of the study in JACK were previously reported in Paul & Quintero-Duran (2015). Figure 4 illustrates the overall assessment score for the simulation of the bed moving task in EMA.

overall score summation:	**78**
posture score summation:	**2**
posture scores	2
twist score	0
bend score	0
reach score	0
force score summation:	**55**
finger forces	0
body forces	55
load score summation:	**20.5**
repositioning	0
holding	0
carrying	0
pushing & pulling	20.1
extra score summation:	**0.5**
influences by working on moving parts	0
accessibility	0
vibrations, momentum, forces	0
joint postures	0
other stesses and strains	0.1

Figure 4. EAWS workload assessment score in EMA.

A grand score of 78 was obtained for the simulation of moving a hospital bed, given the parameters established. According to the EAWS overall evaluation scheme with a three-zone rating system, a final ergonomic assessment score of 78 falls into the red zone (>50 points), and represents a high risk for the development of MSD, so the task should be avoided or modified.

3.1. Posture score

For the evaluation, the software considers posture duration [s], and frequency; however, a sequence is not considered, therefore recovery aspects are not taken into account (Schaub et al. 2013). For the present ergonomic assessment of hospital bed moving, a posture score summation of 2 was obtained.

3.2. Force score

For action forces, a total score of 55 was obtained for the simulation. In this case, the score corresponds entirely to the whole body forces and does not reflect forces of the hand–finger system. Ergonomic parameters such as muscular force, force type (arm/body force or finger force) and type wrist joint/kickback level (light, heavy, very heavy) are adjustable in the software and must be specified for each task. Duration and frequency are calculated by the software according to the complete simulation, the specified shift time and number of cycles per shift (an assumption of 10 was chosen for the present simulation). The intensity of the force exertion was indicated as being 350N, which corresponds to the magnitude used in the Jack simulation.

3.3. Load score

For the part on manual materials handling, a total score of 20.5 points was obtained. This score fully corresponds to the pushing/pulling task. In the EAWS evaluation system, the load section takes into account the weight of loads, the corresponding posture according to the task, frequency and duration of the task and the working conditions. The weight of the hospital bed was estimated as 250 Kg, which resembles the weight of a standard occupied hospital bed (Schaub et al. 2013).

3.4. Simulation pathway

Figure 6 illustrates a spaghetti diagram for the entire simulation pathway. This visual representation of the workflow allows the user to identify potential critical areas that place high physical demands on the worker. The red dots in Figure 6 represent events where the worker is required to transport the bed around corners, or bed start-up pushing is required after straight transportation is stopped. In addition, as the spaghetti chart presents a clear and logical representation of the walking path, it is possible to identify pathways with longer distances when transporting the bed between different wards or medical areas.

In order to establish the transport route for the hospital bed in the simulation, the study conducted by Daniell, Merrett, and Paul (2014) was considered. Movements and variables such as straight walking along corridors, 90° turns when transporting the bed around corners and 90° turns to enter/exit lifts where included in the simulation.

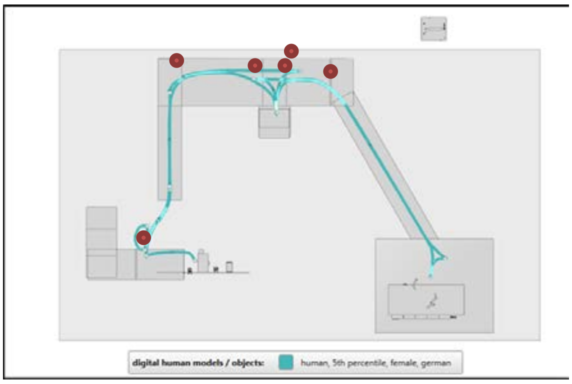

Figure 6. Spaghetti diagram for simulation in EMA.

4. Discussion

Health care workers such as nurses experience a high incidence rate of work-related musculoskeletal disorders, in particular, lower back pain among health care workers is identified as a significant issue with an increased risk of injury when compared to other professions (Daniell et al. 2014). It is therefore important to fully understand the physical strain imposed by moving hospital beds. This can be best achieved through parameter variation in a simulation system. In general, Siemens Jack and EMA are well suited for this purpose. The analysis however poses challenges, as they are explained below.

Given that JACK is not an intrinsically dynamic system, complex interface conditions such as the bed wheel rolling resistance, wheel friction, wheel slip and overall force transmission between the bed and an operator cannot be simulated in the system. Instead, additional methods and external, likely empirical or experimental data are required as input for Jack to provide parameters for the biomechanical ergonomic assessment. EMA on the other hand incorporates dynamic methods, enabling the software to consider external factors such as floor friction. This functionality however is not well documented and doesn't accept physical parameter input; instead it works with unspecified categories.

While OWAS and RULA posture evaluation methods provide some rough insight into postural and related design deficiencies, they assess a static condition and do not consider the problematic dynamic nature of the task.

In EMA, asymmetric effects such as trunk rotation, lateral bending and far reach (twist, bend and reach scores) were not realistically considered.

During bed rotation movements (e.g. pushing around corners, sideways or in a confined space), lateral bending or trunk rotation can be expected. This is illustrated in Figure 5, representing the human model pushing the hospital bed between corridors towards an elevator, where further twisting movements can be present. These events are reported as common issues in real workplace scenarios, however, they were reported with a "0" score in the simulation results. This discrepancy could be attributed to the over-simplification of complex operations and movements performed by the digital model, where the software automatically determines the shortest walkway and the "best" boundary conditions of the work task, which may not always correspond to real movements and conditions in the workplace.

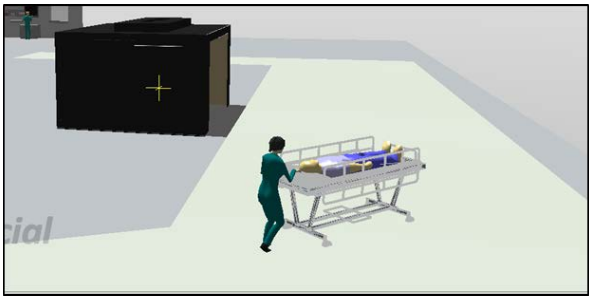

Figure 5. Typical cornering movements simulated in EMA.

From spine values reported in EMA for the simulation, it can be evidenced that only variability in thoracic, lumbar and pelvis flexion angles was reported, while thoracic and lumbar rotation angles were reported as 0. This result supports the statement that the software does not realistically represent actual worker movements

JACK's low back analysis based on NIOSH clearly identified a critical compression force at L4/L5 beyond established limits, suggesting modification in the job task by comparison with a recommended action limit of 500 N suggested by McGill, Norman, Yingling, Wells & Neumann (1998); and indicating that there was a risk for low back injuries. However the value determined by JACK was below the recommended exposure limits proposed by Gallagher & Marras (2012). According to this study, the maximum permissible limit for occasional exposure to shear loading is 1000N, while a 700N shear limit applies for an exposure to repetitive shear loading. Nevertheless, it is important to consider that in the later study there was limited representation of the female population in the experiment, in which case, the shear tolerance values may not adequately apply to the current simulation.

Calculations of body weight and hand forces effects are used in JACK to estimate muscle activity based on studies of Raschke, Martin & Chaffin (1996), where the Distributed Moment Histogram method is used to estimate muscle tensions according to the distribution of moments in the torso. The lower back analysis in JACK predicts muscle tension in the erector spine, however, as this is a simplified model, other trunk muscles are reported inactive, as it is the case for the external/internal oblique, latissimus dorsi and the rectus abdominus. This analysis of muscle tension contradicts common sense and findings of other studies such as Daniell et al. (2014), where it was found that a large number of muscles are active in hospital bed pushing, and potentially significant contribution to spinal load may stem from internal oblique activity.

4.1. Validity range in EMA

With the purpose of identifying boundary conditions and potential limitations on the acceptable range of input parameters in EMA, an assessment of input values range was conducted. The two input parameters considered were pushing force and hospital bed weight. These values were adjusted in the simulation of individual tasks, while maintaining the remaining parameters unchanged. The correspondent EAWS score was recorded and a graph was generated. Figure 7 shows the results for the EAWS score according to the value of the pushing force assessed.

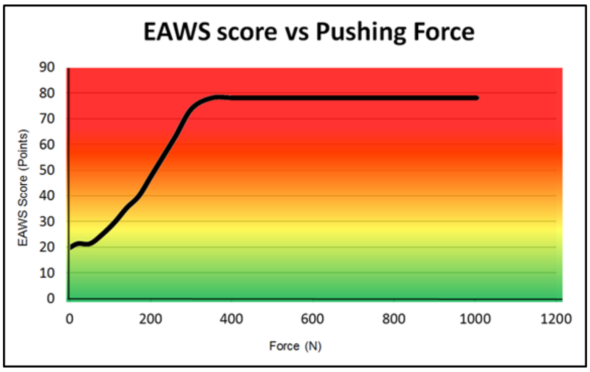

Figure 7. EAWS score over exerted force in EMA.

According to these results, there are no changes in the EAWS score above 300N of pushing force. This indicates that there are boundary conditions for this parameter regarding changes in the results, however, this fact is not defined and clearly stated in the method. The traffic light scheme used in the EAWS evaluation system was incorporated in the graph and indicates that for forces around 200N there is a transient area between the yellow and the red zone.

Figure 8 illustrates the results for the EAWS score according to the values of hospital bed weight. It is evidenced that above 350kg the EAWS result is constant.

For the two input values assessed, the boundary conditions may vary between the methods integrated in EMA. However, as it is not possible to obtain individual results for the methods, potential discrepancies and conflicts between acceptable value parameters from the different methods remain unknown.

In order to analyse how anthropometric conditions influence ergonomic design and measurements, digital humans can be scaled based on different anthropometric databases included in the JACK simulation software. Peoplesize Australian population and the Chinese population databases were used for the simulation in JACK. However, it was not possible to generate custom mannequins for the simulation in EMA (Version 1.5.1), as only predetermined human models are available for analysis in the software.

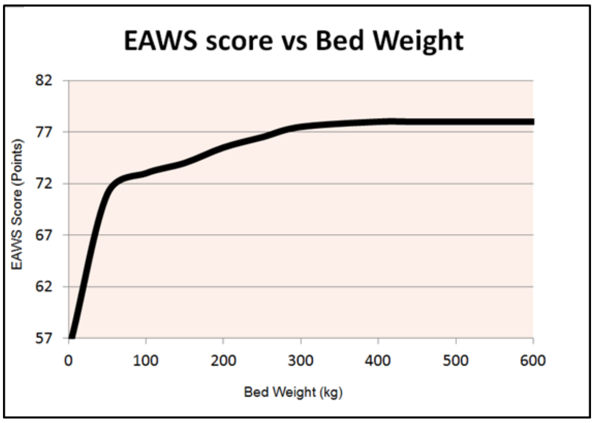

Figure 8. EAWS score over bed weight.

4.2. Ergonomic assessment methods

A comparison of the ergonomic methods/tools used in the two DHMs is presented in Table 1. Kamusella (2015) discussed a potential limitation applicable to any DHM used for the ergonomic assessment of job tasks. As traditional methods based on purely observational studies are integrated into the DHM, there are potential discrepancies between these subjective observations and the calculations obtained in the DHM. For instance, these discrepancies can be attributed to the level of detail in angular measurements.

Table 1: Ergonomic methods in JACK and EMA.

Area	JACK		EMA	
Working posture	• OWAS • RULA	Jack Task Analysis Tool Kit	• OWAS • RULA • EN 1005-4:2005+A1:2008 • ISO 11226:2000	EAWS
Action forces	• Force solver		• EN 1005-3:2002+A1:2008	
Manual materials handling	• Lower Back Analysis tool (NIOSH, L4/L5 Forces)		• Key Item Method HHT(KIM) • EN 1005-2:2003	
Repetitive loads of the upper limbs			• OCRA • KIM on manual work processes • EN 1005-5:2007 • ISO 11228-3:2007	
Overall physical workload modelling	• Static strength prediction • Metabolic energy expenditure • Fatigue recovery		• EN 1005-4:2005+A1:2008 • ISO 11226:2000 • Toyota	

A posture can be classified as straight using the traditional visual assessment, whereas this same posture can be classified as an inclined posture in the DHM, as for the latter, the level of precision in the measurements is higher. For this reason, the integration of traditional ergonomic methods in DHM is problematic and requires further discussion in the academic discipline, with potential modification and adjustment of common methods when applied to DHM.

Regarding the integration of tools in EAWS, there is a potential risk of misinterpretation of results as the methods integrated were not originally developed to be used in conjunction with other tools. In addition, parameters and measurements established for one method can differ from the other methods' principles. These discrepancies can result in a conflict of outcomes; however, the inconsistencies are not shown in the final score. In contrast, the individual results presented in JACK allow the user to assess the consistency of the data as the underlying principles of the methods are known.

5. Conclusion

Moving hospital beds is one of the leading physical tasks for complaints of musculoskeletal pain for health care workers; thus it is important to study and assess how this task may impact biomechanical loading and effect the risk of low back pain and musculoskeletal disorders. However, hospitals are highly regulated environments that make it difficult to conduct real type research studies. For this reason, DHM systems such as JACK and EMA are well suited for ergonomic analysis through parameter variation in a simulated environment. Results from both tools indicate the need for adjustments in working conditions, as with the values of the parameters established, the task of moving hospital beds presents a high risk for the development of MSDs among healthcare workers.
Nevertheless, this analysis in both DHM tools has limitations that need to be considered when interpreting the results.

Complex interface conditions such as the influence of handle design, floor materials, front caster locks, effects of wheel size, and wheel rolling resistance, cannot be simulated in the DHMs studied. In addition, neither the psychosocial nor environmental stressors were considered in the simulation, which impose a limitation for achieving comparability with the outcomes from real world experiments and studies.

Given the limitations presented in both human simulation packages, it can be concluded that a simulated assessment of the biomechanically complex task of pushing a hospital bed remains limited in JACK and EMA and can only provide a direction for further research.

Moreover, limitations of this study in itself must be noted. The work was carried out by one single researcher in a sequential study design, and simulations were not repeated. Furthermore, only one exemplary hospital bed type was used for the study. Thus further, more substantial simulations are required to further explore differences between the systems, and confirm findings of this study.

Acknowledgement

This study was carried out with an educational software license granted by imk automotive GmbH. Brian Merton kindly supported the EMA simulations.

References

Al-Eisawi K, Kerk C, Congleton J, Amendola A, Jenkins O & Gaines W, 1999. Factors affecting minimum push and pull forces of manual carts. Applied ergonomics, 30(3), 235-245.

Aptel M & Cnockaert J C, 2002. Stress and work-related musculoskeletal disorders of the upper extremities. France: Tutb Newletter, 19(20), 50-56.

Australian Bureau of Statistics, 2012. Reflecting a Nation: Stories from the 2011 Census. Retrieved from: http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/2071.0main+features902012-2013.

Australian Government, 2006. Work-related musculoskeletal disease in Australia Retrieved from http://www.safeworkaustralia.gov.au/sites/SWA/about/Publications/Documents/119/WorkRelatedMusculoskeltalDisorders_2006Australia_2006_ArchivePDF.pdf.

Bennett AI, Todd AI & Desai SD, 2011. Pushing and pulling, technique and load effects: An electromyographical study. Work, 38(3), 291-299. doi:10.3233/WOR-2011-1132.

Bhattacharya A & McGlothlin JD, 2012. Occupational ergonomics: theory and applications (Vol. 2nd). Boca Raton, FL: CRC Press.

Bubb H, 2007. Future applications of DHM in ergonomic design. In: Digital Human Modeling, Springer, 779-793.

Cao W, 2011. Ergonomic assessment of sonography workplace and posture parameters using digital human modeling. Available from ProQuest Dissertations & Theses Global. Retrieved from: http://search.proquest.com/docview/921610333?accountid=13380.

Chaffin DB, 2007. Human motion simulation for vehicle and workplace design. Human Factors and Ergonomics In Manufacturing, 17(5), 475-484. doi:10.1002/hfm.20087.

Daniell N, Merrett S & Paul G, 2014. Effectiveness of powered hospital bed movers for reducing physiological strain and back muscle activation. Applied Ergonomics, 45(4), 849-856. doi:10.1016/j.apergo.2013.11.001.

Davis KG & Kotowski SE, 2015. Prevalence of Musculoskeletal Disorders for Nurses in Hospitals, Long-Term Care Facilities, and Home Health Care: A Comprehensive Review. Human Factors, 57(5), 754-792. doi:10.1177/0018720815581933.

Fritzsche L, Jendrusch R, Leidholdt W, Bauer S, Jäckel T & Pirger A, 2011. Introducing ema (Editor for Manual Work Activities)–A New Tool for Enhancing Accuracy and Efficiency of Human Simulations in Digital Production Planning. In: Digital Human Modeling, Springer, 272-281.

Gallagher S & Marras WS, 2012. Tolerance of the lumbar spine to shear: A review and recommended exposure limits. Clinical Biomechanics, 27(10), 973-978. doi:10.1016/j.clinbiomech.2012.08.009.

Garg A, Chaffin DB & Herrin GD, 1978. Prediction of metabolic rates for manual materials handling jobs. The American Industrial Hygiene Association Journal, 39(8), 661-674.

Ha C, Cao W & Khasawneh MT, 2014. Ergonomic Assessment of Patient Under-arm Lifting Technique Using Digital Human Modeling. IIE Annual Conference. Proceedings. Available from ProQuest Dissertations & Theses Global. Retrieved from: http://search.proquest.com/docview/1615119369?accountid=13380.

Miller H, 2003. Ergonomics: Good News for Healthcare Workers. Retrieved from: http://www.hermanmiller.com/hm/content/research_summaries/pdfs/wp_ergogoodnews0503.pdf.

Imk (innovationen-methoden-konzepte), 2015. EMA-Editor of Human Labor. Retrieved from http://www.ema.imk-automotive.de/wer-ist-ema.html.

Kamusella C, 2015. Methodenumsetzung in der digitalen Ergonomie. Unpublished manuscript.

Karhu O, Kansi P & Kuorinka I, 1977. Correcting working postures in industry: a practical method for analysis. Applied Ergonomics, 8(4), 199-201.

Kee D & Seo SR, 2007. Musculoskeletal disorders among nursing personnel in Korea. International Journal of Industrial Ergonomics, 37(3), 207-212. doi: 10.1016/j.ergon.2006.10.020.

Knapik G & Marras W, 2009. Spine loading at different lumbar levels during pushing and pulling. Ergonomics, 52(1), 60-70. doi:10.1080/00140130802480828.

Lee YJ & Aruin AS, 2015. Effects of asymmetrical stance and movement on body rotation in pushing. Journal of Biomechanics, 48(2), 283-289. doi:10.1016/j.jbiomech.2014.11.032

Marras WS & Granata KP, 1997. Spine loading during trunk lateral bending motions. Journal of Biomechanics, 30(7), 697-703. doi:10.1016/S0021-9290(97)00010-9.

McGill S, Norman R, Yingling V, Wells R & Neumann P, 1998. Shear happens! Suggested guidelines for ergonomists to reduce the risk of low back injury from shear loading. In: Proceedings of the 30th annual conference of the human factors association of Canada, 157-161.

Mehta RK, Horton LM, Agnew MJ & Nussbaum M A, 2011. Ergonomic evaluation of hospital bed design features during patient handling tasks. International Journal of Industrial Ergonomics, 41(6), 647-652. doi: 10.1016/j.ergon.2011.07.005.

Open Ergonomics Ltd, n.d. Effective ages of the anthropometric data in PeopleSize 2008. Retrieved from: http://openerg.com/psz/anthropometric_dates.html.

Paul G, Reed MP & Wang X, 2012. Digital human modelling for vehicle design and manufacturing. Geneva, Switzerland: Inderscience Enterprises Ltd.

Paul G & Quintero-Duran M, 2015. Ergonomic assessment of hospital bed moving using DHM Siemens JACK. In Lindgaard, Gitte & Moore, Dave (Eds.) Proceedings of the 19th Triennial Congress of the International Ergonomics Association, International Ergonomics Association, Melbourne, Vic.

Petzäll K, Berglund B & Lundberg C, 1994. Beds used at a university hospital--a study of functions, problems and requirements. Scandinavian journal of caring sciences, 9(3), 181-186.

Petzäll K & Petzäll J, 2003. Transportation with hospital beds. Applied ergonomics, 34(4), 383-392.

Raschke U, Martin BJ & Chaffin DB, 1996. Distributed moment histogram: A neurophysiology based method of agonist and antagonist trunk muscle activity prediction. Journal of Biomechanics, 29(12), 1587-1596.

Safe Work Australia, 2013a. Australian Workers' Compensation Statistics, 2012–13. Retrieved from http://www.safeworkaustralia.gov.au/sites/SWA/about/Publications/Documents/897/australian-workers-compensation-statistics-2012-13.pdf.

Safe Work Australia, 2013b. Sizing up Australia- The next step. Chapter 1: Report Summary. Retrieved from: http://www.safeworkaustralia.gov.au/sites/SWA/about/Publications/Documents/845/Sizing-Up-Australia-Chapter1-Report-Summary.pdf.

Samson A, 2009. Digital human modeling for ergonomic assessment of patient lifting by paramedics. Available from ProQuest Dissertations & Theses Global. Retrieved from: http://search.proquest.com/docview/305111769?accountid=13380.

Samson A, Salaskar S, Khasawneh MT, Wang S & Srihari K, 2009. Digital Human Modeling in Healthcare Systems: Overview, Opportunities, and Applications. In: IIE Annual Conference Proceedings, Institute of Industrial Engineers-Publisher, 844.

Schaub K, Caragnano G, Britzke B & Bruder R, 2013. The European Assembly Worksheet. Theoretical Issues in Ergonomics Science, 14(6), 616-639. doi:10.1080/1463922X.2012.678283.

Siemens, 2014. Jack and Process Simulate Human. Retrieved from: http://www.plm.automation.siemens.com/en_us/products/tecnomatix/manufacturing-simulation/human-ergonomics/jack.shtml.

Waters T, Lloyd JD, Hernandez E & Nelson A, 2011. AORN Ergonomic Tool 7: Pushing, Pulling, and Moving Equipment on Wheels. AORN Journal, 94(3), 254-260. doi:10.1016/j.aorn.2010.09.035.

Ziolek SA, Kruithof Jr PC, 2000. Human modeling & simulation: A primer for practitioners. Proceedings of the Human Factors and Ergonomics Society Annual Meeting July 2000, vol.44 no.38, 825-827.